(12) UK Patent Application (19) GB (11) 2 131 175 A

(21) Application No 8226332
(22) Date of filing 15 Sep 1982
(43) Application published 13 Jun 1984
(51) INT CL³ G01K 13/00
(52) Domestic classification G1N 1A3B 1D4 7A1 ADC G1D 22
(56) Documents cited None
(58) Field of search G1N G1D

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(54) **Measuring temperatures and heat transfer coefficients**

(57) A probe is plugged into the wall of a combustion chamber, so that its distal end effectively forms part of the wall of that chamber. The probe contains two separate elongate bodies (3, 4) largely surrounded by an air gap and each containing two thermocouples (8, 9; 10, 11) one near the distal end and the other at the proximal end. The thermal conductivities of the two bodies are different and known, and the proximal end of the probe can be kept at a controlled temperature by cooling fluid from 7. From the thermocouple measurements and the known thermal conductivities can be calculated the heat fluxes in the two bodies, and hence the temperature in the enclosed space and/or the heat transfer coefficient.

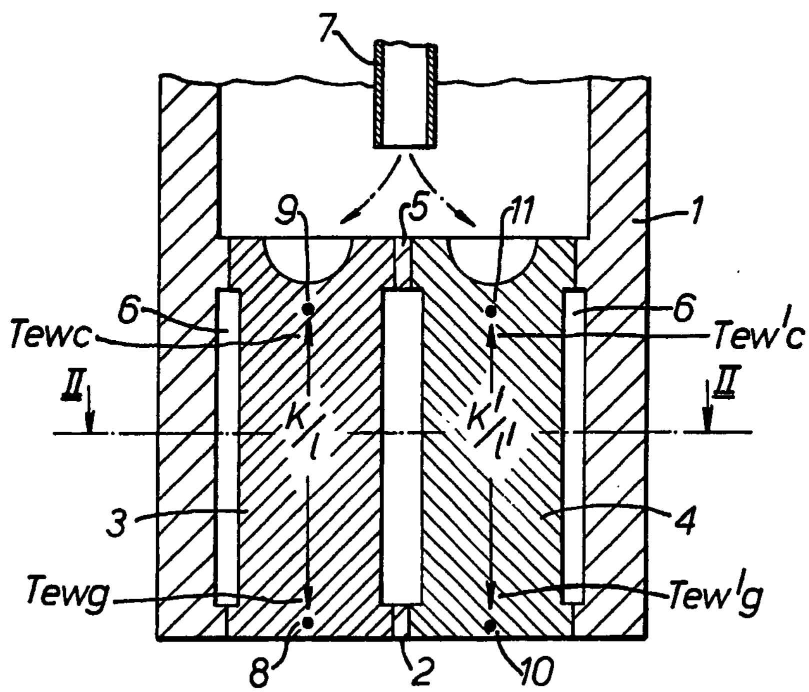

FIG. 1.

The drawings originally filed were informal and the print here reproduced is taken from a later filed formal copy.

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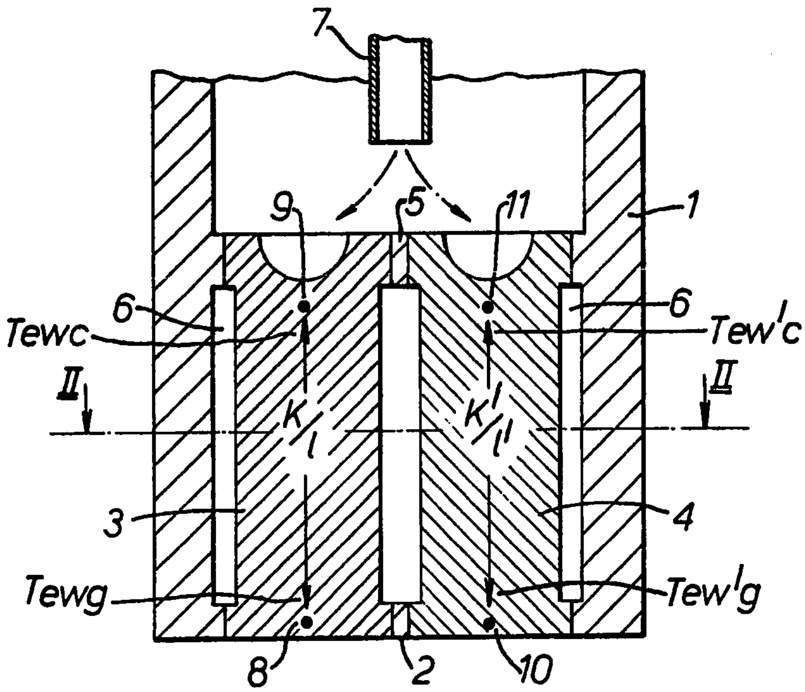

FIG. 1.

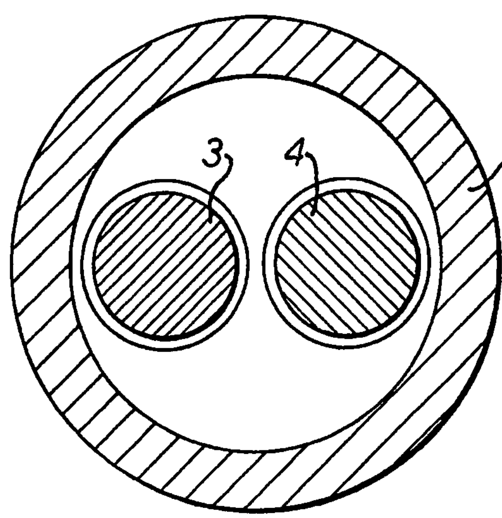

FIG. 2.

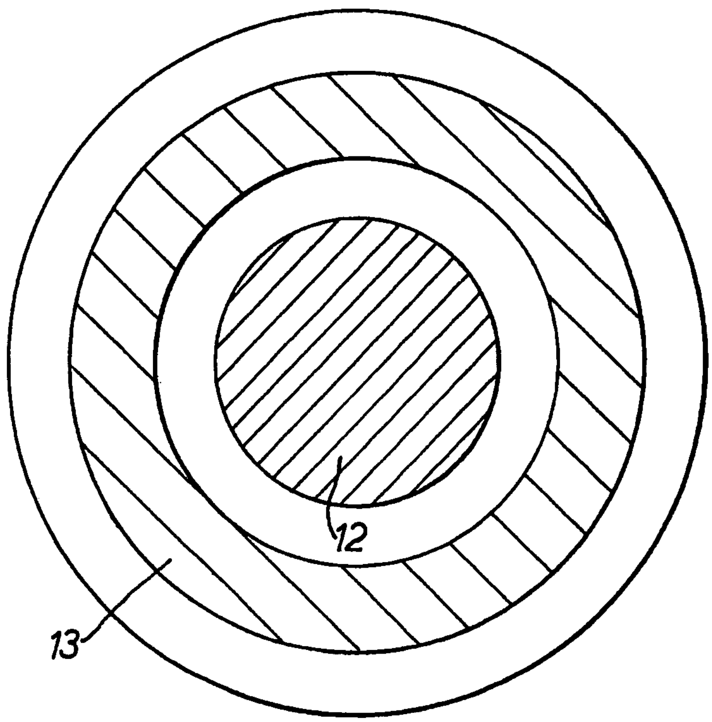

FIG. 3.

SPECIFICATION

A method of and apparatus for measuring temperatures and heat transfer coefficients

This invention relates to a method of and apparatus for measuring temperatures and heat transfer coefficients. It is primarily concerned with such measurements in reciprocating internal combustion engines, where it is important to assess the thermal loading of various components.

At present, the experimental techniques for such measurements are difficult to use or interpret, and often unreliable. The measurement of gas-to-metal heat transfer coefficients usually involves measuring the periodic variation of the wall surface temperature, and using it as a boundary condition for solving the Fourier differential equation that describes the temperature pattern in the wall as a function of time and location. This technique demands very thin film probes and quite sophisticated mathematical treatment of the measured data.

In another method, the steady-state local heat flux from the steady-state wall temperature gradient is measured. This is obtained by evaluating the measured temperature distribution with the solution of the Laplace equation, or by means of a steady-state heat flux probe. Information on the relevant mean gas temperature is then required, but the existing methods for measuring cylinder gas temperatures, such as the velocity of sound method or the infra-red method, are usually very difficult to put into practice and to interpret.

It is the aim of this invention to provide means for determining gas temperatures in a closed space such as a combustion chamber, and the gas-to-metal heat transfer coefficient at that zone, by essentially simple apparatus and straightforward and brief calculations from the data it produces.

According to one aspect of the present invention there is provided a method of measuring temperature wherein two adjacent heat escape paths with known and different thermal conductances are arranged to lead from the source whose temperature is to be determined, the temperature gradient in each path is measured by sensing devices near and remote from the source, the heat flux in each path is ascertained from the gradients and the conductances, and the source temperature is calculated from the fluxes and the measured temperatures from the sensing devices.

According to another aspect of the present invention there is provided a method of determining a heat transfer coefficient wherein two adjacent heat escape paths with known and different thermal conductances are arranged to lead from a zone where a heat transfer coefficient is to be determined, the temperature gradient in each path is measured by sensing devices near and remote from the zone, the heat flux in each path is ascertained from the gradients and the conductances, and the heat transfer coefficient is calculated from the fluxes and the measured temperatures from the sensing devices.

In both cases, in the final calculation the temperatures from the sensing devices near the source or zone are used.

If the heat transfer coefficient is determined first, an alternative calculation can give the temperature to be measured.

These methods are particularly applicable to the measurement of gas temperatures in an enclosed space, or the determination of a gas-to-metal heat transfer coefficient such as in the combustion chamber of an internal combustion engine.

According to a further aspect of the present invention there is provided apparatus for carrying out such methods, comprising two elongate bodies of known and differential thermal conductances, temperature measuring devices at opposite ends of the bodies, and means for mounting said bodies adjacent each other with one end of each exposed to the source or zone to be measured.

Preferably, the temperature measuring devices will be thermocouples. To ensure significant measurable temperature gradients, there may be means for cooling or controlling the temperature of the other ends of said bodies remote from the source or zone.

In order to ensure substantially uni-dimensional heat conduction, there will preferably be an air gap between most of the mounting means and said bodies, and between the bodies themselves. These may be of similar shape and arranged side-by-side, or there could be one body coaxially within the other, which would be of cylindrical form.

For a better understanding of the invention some embodiments will now be described, by way of example, with reference to the accompanying drawing, in which:

Figure 1 is an axial section of a temperature measuring probe;

Figure 2 is a cross-section of the probe on the line II-II of Figure 1; and

Figure 3 is a cross-section of an alternative probe.

The probe of Figures 1 and 2 has a generally cylindrical shell 1 of high alloy steel, which is of poor heat conductivity. This will be inserted like a plug into the wall of a cylinder so that its closed end face 2 will provide part of the internal surface of that cylinder and be directly exposed to the combustion gases. Two generally cylindrical bodies 3 and 4 of similar shape but of different materials are arranged side-by-side within the shell 1 and at their lower ends, as seen in the Figure, they fit closely into two circular holes in the end face 2. These ends are therefore also exposed to the combustion gases. At the other ends, the bodies 3 and 4 are located by a web 5 across the shell, and in between they are of slightly reduced diameter to create a substantial air gap 6 between themselves and the shell 1. The inner ends of the bodies 3 and 4 are centrally

recessed and exposed to cooling fluid, usually water, from a source 7. This enables the temperatures on the probe surfaces to be controlled.

Each body has two thermocouples, preferably of NiCr-Ni material, one near the end exposed to the gas and the other near the opposite end. These are referenced 8, 9, 10 and 11, and they read wall temperatures Tewg, Tewc; Tew'g, Tew'c as shown in Figure 1. The thermal conductances of the bodies 3 and 4 differ substantially, that of the body being K/1 and that of the body 4 being K'/1', also as indicated in Figure 1, and these are precisely calibrated beforehand. Therefore, the corresponding heat flux q and q' in each body can be calculated from the measured wall temperatures. Tewg, Tewc, Tew'g, Tew'c, as:-

$$q = \frac{K}{1}\,(Tewg - Tewc) \quad \text{in body 3} \qquad (1)$$

$$q' = \frac{K'}{1'}\,(Tew'g - Tew'c) \quad \text{in body 4} \qquad (2)$$

However, both elements are facing the same gas-side boundary condition, i.e. the same mean effective gas temperature Teg and the same heat transfer coefficient heg. Hence:-

$$q = heg\,(Teg - Tewg) \quad \text{in body 3} \qquad (3)$$

$$q' = heg\,(Teg - Tew'g) \quad \text{in body 4} \qquad (4)$$

Manipulation of equations (3) and (4) yields:-

$$q - q' = heg\,(Tew'g - Tewg) \qquad (5)$$

Therefore the heat transfer coefficient heg can be found as:-

$$heg = (q-q')/Tew'g - Tewg) \qquad (6)$$

in which Tewg, Tew'g are the measured wall surface temperatures; whereas q and q' are also known from the measured temperature gradients, equations (1) and (2).

From the calculated heat transfer coefficient heg, the mean effective gas temperature Teg thus can also be obtained as:-

$$Teg = (q/heg) + Tewg \qquad (7)$$

or

$$Teg = (q'/heg) + Tew'g \qquad (8)$$

Alternatively, by eliminating heg from equations (3) and (4) one can arrive at:-

$$Teg = \frac{q\,Tew'g - q'Tewg}{q - q'} \qquad (9)$$

and thus determine the effective mean gas temperature without first ascertaining the heat transfer coefficient.

Figure 3 shows an alternative construction in which, instead of two similarly shaped bodies, there is a solid cylindrical body 12 coaxially within a hollow cylindrical body 13, with an air gap between as much of them as possible, and also surrounding the outer body 13. Various other configurations may be adopted for special purposes.

CLAIMS (Filed on 15.9.83.)

1. A method of measuring temperature wherein two adjacent heat escape paths with known and different thermal conductances are arranged to lead from the source whose temperature is to be determined, the temperature gradient in each path is measured by sensing devices near and remote from the source, the heat flux in each path in ascertained from the gradients and the conductances, and the source temperature is calculated from the fluxes and the measured temperatures from the sensing devices.

2. A method of determining a heat transfer coefficient wherein two adjacent heat escape paths with known and different thermal conductances are arranged to lead from a zone where a heat transfer coefficient is to be determined, the temperature gradient in each path is measured by sensing devices near and remote

from the zone, the heat flux in each path is ascertained from the gradients and the conductances, and the heat transfer coefficient is calculated from the fluxes and the measured temperatures from the sensing devices.

3. A method as claimed in claim 1 or 2, wherein only the measured temperatures from the sensing devices near the source are used in the final calculation.

4. A method as claimed in claim 2, or claims 2 and 3, wherein the temperature of said zone is determined from the calculated heat transfer coefficient, an ascertained heat flux and a measured temperature.

5. Apparatus for carrying out the method of any preceding claim, comprising two elongate bodies of known and different thermal conductances, temperature measuring devices at opposite ends of the bodies, and means for mounting said bodies adjacent each other with one end of each exposed to the source or zone to be measured.

6. Apparatus as claimed in claim 5, wherein the temperature measuring devices are thermocouples.

7. Apparatus as claimed in claim 5 or 6, and further comprising means for cooling or controlling the temperature of the other ends of said bodies remote from the source or zone.

8. Apparatus as claimed in claim 5, 6 or 7, wherein said bodies are supported by mounting means having contact at opposite ends, leaving an air gap around them between said ends.

9. Apparatus as claimed in any one of claims 5 to 8, wherein said bodies are of similar shape and mounted side by side.

10. Apparatus as claimed in any one of claims 5 to 8, wherein one body is arranged co-axially within the other body.

11. Apparatus for measuring temperature or determining a heat transfer coefficient substantially as hereinbefore described with reference to Figures 1 and 2 or Figure 3 of the accompanying drawings.

Printed for Her Majesty's Stationery Office, by Croydon Printing Company Limited, Croydon, Surrey, 1984.
Published by The Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from which copies may be obtained.